Spark Ignited TWC Stoichiometric CNG Engines

Opportunities for Extremely Low Emission Medium/Heavy Duty GM CNG Engines in Class 3 – 6 Vehicles which meet MY 07 Heavy Duty Emissions Standards.

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Presentation Outline

1. Review current Teleflex*GFI*/GM MY 03 production launch of the CNG 6.0 L T-610 cargo and passenger vans, and incomplete cab and chassis vehicles up to 12,200 lbs GVWR.
2. Review the recent AQMD project, which is an adjunct to the GM T-610 production program, to develop advanced emissions control systems for the 6.0 L CNG engine, and has resulted in extremely low emissions for 6.0 L engine
3. Discuss the opportunities and benefits of expanding this advanced emission control technology into the full range of Class 3 – 6 vehicles, and positioning the technology relative to diesel.

TGFI/GM CNG T-610
MY 03 PRODUCTION

Four Models Certified:

- **Complete Box Van – Dedicated CNG**
- **Complete Box Van – Bi-fuel CNG/Gasoline**
- **Incomplete Cutaway Chassis – Dedicated CNG**
- **Incomplete Cutaway Chassis – Bi-fuel CNG/Gasoline**

Specifications:

All vehicles equipped with 6L V8 SI engine, 300 HP on gasoline

Complete box vans 8600lbs and 9600 lbs GVWR, ALVW<8500

Incomplete cutaway 12,200 lbs GVWR

Engine Certification Options

CARB g/bhp.hr				EPA g/bhp.hr				
Standard	NMHC+NOx	CO	HCHO	Standard	NMHC+NOx	CO	HCHO	
LEV I ULEV	2.5	14.4	0.050	Fed ULEV	2.5	7.2	0.025	
LEV I SULEV	2.0	7.2	0.025					
[LEV II] LEV Fed '04 Option 1	1.5	14.4	0.050	CFF LEV Fed '04 Option 1	1.5	14.4	0.050	Production Gasoline Cert Level
[LEV II] ULEV Fed '04 Option 1	1.5	7.2	0.025	CFF ULEV Fed '04 Option 1	1.5	7.2	0.025	
[LEV II] '05 ULEV	1.0	14.4	0.050	CFF ULEV Fed '05 Option 3*	1.0	7.2	0.025	Production CNG Cert Level
[LEV II] 05 SULEV	0.5	7.2	0.025	* Incompletes only. Requires completes as Cal LEV chassis cert				
2007 and Later	0.2 g/bhp.hr NOx 0.14 g/bhp.hr NMHC			2007 and Later	0.2 g/bhp.hr NOx 0.14 g/bhp.hr NMHC			

GM T610 Engine Emission Results CNG	NMHC + NOx	CO
	0.296 incl. Assgnd DF	1.66 incl. Assgnd DF

AQMD Low NOx Project

Awarded under the NGNGV Program, supported by AQMD

Objectives

As an adjunct to the production GM T-610 CNG program, develop a low NOx GM 6.0L CNG medium duty engine which will have NOx emissions at or below:

- 0.5 g/bhp.hr
- 0.2 g/bhp.hr

Project Team:

Teleflex GFI control systems INC.

ENGELHARD

GM

Baseline Emissions Data Collected

Baseline emissions data required to determine the advanced catalysts design:

- Transient cycle data, second by second, for emissions components, engine out, cat out, cat temp traces, A/F ratios, exhaust flow rates
- Catalyst efficiency tests, raw emissions over steady state engine conditions, temps, A/F ratios

Areas where Emissions Improvement can be Achieved

Two major area of NOx breakthrough determined where emissions improvement can be achieved:

- Cold transient NOx spike, caused by insufficient temperature
- Cold transient NOx breakthrough caused by high exhaust flow rates. Insufficient residence time at this point in the cycle

SULEV Systems Include State-of-the-Art Engine Designs and Emission Control Systems

Advanced Emission Control Technologies include:

- **Advanced thermally stable, oxygen storage materials**
- **In many cases, layered TWC coating architectures**
- **In some cases, HC adsorber functions**
- **High cell density substrates**
- **Fast response oxygen sensors**
- **Thermal management hardware including air-gap pipes & low heat capacity manifolds**

Advanced Engine Technologies include:

- **Improved fuel injectors**
- **Variable valve technology**
- **Lean start strategy with spark retard for fast catalyst heat-up**
- **Electrically controlled EGR valve**
- **Advanced control algorithms for precise A/F control**

Strategies for Advanced Catalyst Design

Advanced Catalyst Options:

- Substrate cell density change – U/F cats – enhanced residence time
- Washcoat technology upgrade – trimetal with low and high Pd – enhanced low temperature performance
- Move existing package closer – enhanced low temperature performance
- Close coupled plus U/F cats, with upgraded substrate cell density change
- Calibration options

Advanced Catalysts Selected for test program

Advanced Catalysts Selected:

- Huntsville, Alabama facility –
  600 cpsi/3.5 mil wall NEX 311H1catalyst technology with 30 g/ft3 Pt/Pd/Rh 3/0/1 (current cats 350 cpsi/5.5 mil wall)

- Nienburg, Germany facility –
  600 cpsi/3.5 mil wall OEX-101B catalyst technology with 30 g/ft3 Pt/Pd/Rh 1/2/1

- 600 cpsi/3.5 mil wall OEX-101B with 45 g/ft3 Pt/Pd/Rh 1/2/1

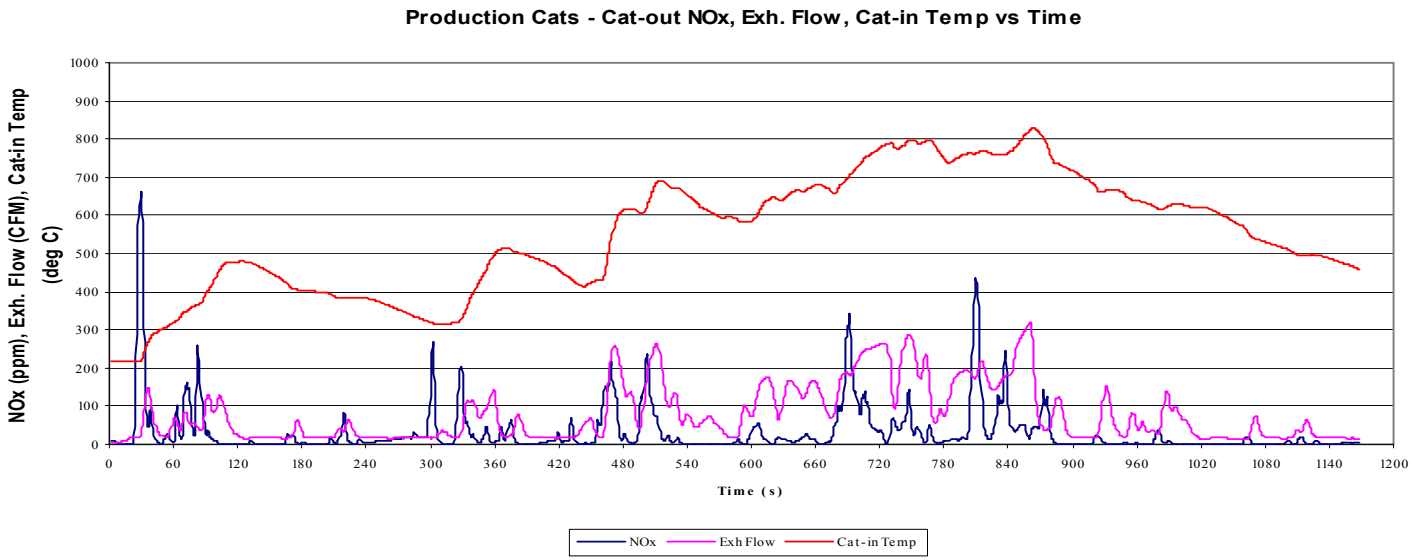
600 cpsi NEX Advanced Cats Comparison with baseline

Test Description	THC g/bhp.hr	CH4 g/bhp.hr	NMHC g/bhp.hr	CO g/bhp.hr	NOx g/bhp.hr	NOx+NMHC g/bhp.hr
Production Converters 125 hrs CNG hot runs average	0.36	0.345	0.015	1.04	0.202	0.217
Advanced Cats NEX 311H1 30G 600 cpsi 125 hrs CNG hot runs average	0.101	0.095	0.006	0.931	0.08	0.086
Emissions Reductions	**72%**	**72%**	**60%**	**11%**	**61%**	**61%**

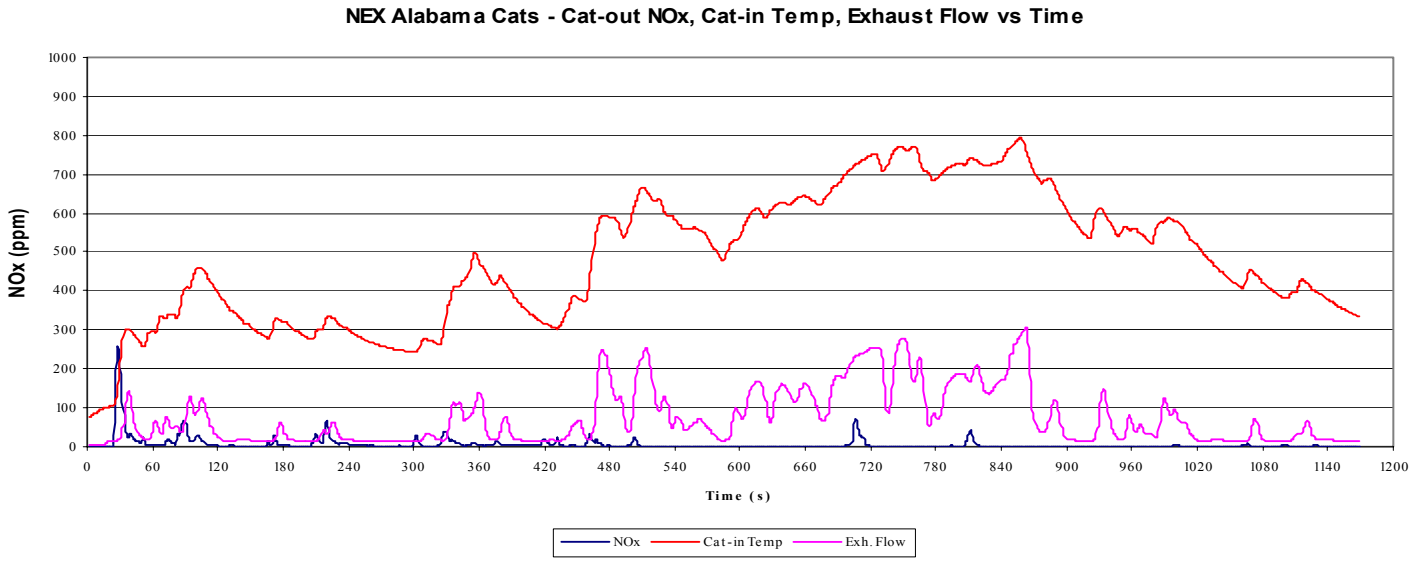
NEX Advanced Catalyst Best Performance Useful life emissions vs Standards

Test Description	THC g/bhp.hr	NMHC g/bhp.hr	CO g/bhp.hr	NOx g/bhp.hr	NOx+NMHC g/bhp.hr
Advanced Catalysts Best performance to date 125 Hr Converters CNG hot runs average	0.101	0.006	0.931	0.08	0.086
EPA Assigned DFs	1.9	2.2	1.6	1.3	
Useful Life Emissions CNG	**0.1919**	**0.0132**	**1.4896**	**0.104**	**0.1172**
CARB Emissions Standards LEV ll 05 SULEV			7.2		0.5
2007 and later Standfards		0.14	7.2	0.2	

NEX Hot Transient NOx Analysis



NOx = 0.202



NOx = 0.079

Conclusions on AQMD Project

- One of the advanced calibration/catalyst systems provides the opportunity for a certifiable engine package which meets the MY 07 heavy duty standards today.
- This is PZEV territory, with NOx levels 1/20th LEV I SULEV
- NOx emissions have been reduced 60%, and methane emissions have also been significantly reduced by 72%
- Brake specific fuel economy remains unchanged with advanced calibration/catalyst systems
- Cost impact of advanced catalyst is expected to be minimal

Opportunities for Deployment of Class 3 – 6 Vehicles meeting 07 standards

- Opportunity to migrate this low emission technology into full range of Class 3 – 6 vehicles with a GM 8.1 L CNG engine
- Developing 525 HP and 560 lb-ft of torque, this engine is an excellent candidate for CNG applications in C-Series trucks, refuse haulers, street sweepers, and bus applications
- Meeting 07 standards will make them cleanest vehicles in their class, making them eligible for grants from MSRC, Moyer, etc.
- Eligibility for grant money to cover incremental costs will be attractive for fleet owners, especially in California

NOx Emissions Comparison
Clean Diesel, Lean Burn CNG, Stoich. CNG

Vehicle Configuration	Useful Life Emissions				
	NOx g/bhp.hr	CO g/bhp.hr	THC g/bhp.hr	NMHC g/bhp.hr	NMHC + NOx g/bhp.hr
GM 6.0 L CNG Advanced TWC Cats.	0.104	1.49	0.19	0.13	0.117
Low Emitting Diesel	3.0				
Conventional Diesel	3.9				
Lean Burn CNG	2.6				

Emissions Comparison
Diesel, Clean Diesel, Lean Burn CNG, Stoich. CNG

Vehicle		**Diesel Euro 2**			**NGV SM**			**Diesel Euro 0**	**Diesel Euro 2 Plus Trap**	**NGV Lean Burn**
Fuel		Commercial diesel			Natural gas			Diesel	Diesel	CNG
Test Period		Oct. 99			Nov. 99			May 00	May 00	June 00
Place		Brussels line 59 & 21			Brussels line 59 & 21			Lausanne	Lausanne	Lausanne
Test weight	tons	17.6	14.8	12.0	19.6	16.8	14.0	11.0	12.5	14.2
Ave. speed	Km/h	16.3	18.3	19.5	17.6	16.2	15.4	15.6	17.0	17.7
Fuel cons.	l/100km	72.4	60.2	56.2	76.0	74.4	69.9	54	45	56
CO2	g/km	1885	1565	1449	1527	1493	1404	1384	1180	1109
Nox	g/km	18.1	14.0	13.4	1.9	1.5	1.9	40.3	14.7	19.9
CO	g/km	3.6	3.4	3.5	0.6	0.7	0.6	11.1	0.28	0.30
THC	g/km	2.0	1.6	1.5	0.1	0.1	0.1	2.4	0.02	0.50

What Have We Learned

- Clean diesel emissions are approaching lean burn H.D. CNG emissions in real world driving conditions
- Lean burn H.D. CNG engines should be calibrated over real world driving cycles if this is the new measurement standard
- 07 capable Stoichiometric H.D. CNG engines with advanced emissions controls have been developed which are an order of magnitude lower in emissions performance than diesel, and probably unbeatable in low emissions performance. Cost impact of the 07 technology is minimal.
- Fuel economy improvements in stoichometric CNG engines may be an attractive approach for combining fuel efficiency with almost zero emissions
- Since stoichiometric CNG technologies are now capable of meeting 07 standards, there are opportunities for near term availability of 07 capable stoichiometric CNG vehicles in the Class 3 – 6 range which should be attractive to fleet operators, and will encourage deployment of increasing numbers of CNG vehicles